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Research Article
Impact of Dynamic Atmospheric Temperature on Dengue Vector-*Aedes aegypti*

[1]S. Ramya, [2]R. Jayakumararaj and [1]K. Neethirajan

[1]Department of Zoology, Yadava College for Men, 625 014 Madurai, India
[2]Department of Botany, Government Arts College, Melur, 625106 Madurai, India

Abstract
Background and Objective: Dengue is common in tropical and sub-tropical climates worldwide, mostly in urban and semi-urban areas. Recently, rural areas are beginning to be affected in developing countries with local variations in risk influenced by rainfall, temperature, relative humidity and unplanned rapid urbanization. In the present study, impact of atmospheric temperature on population of dengue vectors was observed. **Materials and Methods:** *Aedes* species were separated among mosquitoes collected from 5 different selected sites located in Madurai (Anaiyur, Iyer Bungalow, Thabal Thanthi Nagar, Tiruppalai and Oomachikulam) with varying human settlement interface for a period of 2 years from January, 2015 to December, 2016. Data were analysed using Principal Components Analysis (PCA). **Results:** With the raise in temperature, reduction in mosquito population was observed and vice versa. The PCA based interactive model was developed between atmospheric temperature and distribution pattern of the vector population elucidated temperature as positive climatic parameter **Conclusion:** Density of the mosquitoes is significantly influenced by dynamic atmospheric temperature. Such studies could be used as a model to provide dengue outbreak warning.

Key words: Dengue vector, *Aedes aegypti*, atmospheric temperature, mosquito, vector borne disease

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Corresponding Author: R. Jayakumararaj, Department of Botany, Government Arts College, Melur, 625106 Madurai, India

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Vector Borne Diseases (VBDs) account for 17% of the global burden of all infectious diseases. Every year there are more than 1 billion cases and over 1 million deaths due to VBDs[1,2]. Mosquitoes are the most prominent group of insects, both in terms of the number of pathogens transmitted and magnitude of health problems caused[1]. According to the most recent classification of mosquitoes, the family Culicidae (Diptera) includes two subfamilies, 11 tribes, 111 genera and 3523 species in the world fauna[3]. However, only 3 genera viz., *Aedes*, *Anopheles* and *Culex* are of concern to the public health as they transmit disease causing pathogens. Genus, *Aedes* comprises of more than 950 species among them *A. aegypti*, *A. albopictus*, *A. vittatus*, *A. polynesiensis* and *A. scutellaris* have been attributed to the outbreak of Dengue and Chikungunya. The virus responsible for causing dengue is called dengue virus (DENV). Dengue virus is transmitted by female mosquitoes mainly of the species *Aedes aegypti* and to a lesser extent, *A. albopictus*. *Aedes aegypti* originated in Africa, but, is now more common in tropical and subtropical regions of the world, generally dwells in urban and suburban areas[4].

World's fastest growing VBD is dengue, with a 30 folds increase in disease incidence over a span of 50 years. Dengue was first recognized in 1950s during dengue epidemics in Philippines and Thailand. Today, it affects most of the Asian and Latin American countries and has become a leading cause of hospitalization besides death among children and adults. In India, the first epidemic of clinical dengue-like illness was recorded in Chennai in 1780 and the first virologically proved epidemic of Dengue Fever (DF) occurred in Calcutta (now Kolkata) and Eastern Coast of India in 1963-1964. The total number of dengue cases in India has significantly increased since 2001. Gupta *et al.*[5] reported that dengue was endemic in a few southern (Maharashtra, Karnataka, Tamil Nadu and Pondicherry) and Northern States (Delhi, Rajasthan, Haryana, Punjab and Chandigarh). Chen and Wilson[6] reported that recently, it has spread to other states due to human travel besides population growth, rapid urbanization and failures of preventative public-health measures are the major factors for the increase in dengue cases reported so far.

Climate has direct effects on vectors (e.g., abundance, distribution and longevity), hosts (abundance, distribution and behaviour), pathogens (incubation period, replication and lineage) and their interactions. Abundance of mosquito is the key factor that determines the vectorial capacity and the basic reproductive rate[7]. Viral and host factors also play an important roles in the course of infection, however, a fundamental knowledge gap still remains to be filled. A growing number of articles suggest that population density of *A. aegypti* exhibit inter-annual fluctuations that are directly linked to climatic variability. Large-scale longitudinal cohort studies are required to characterize spatial and temporal variations with respect to the distribution and dynamics of the vector. With this background information, the present study was carried out to understand the relationship between the density of dengue vector population and atmospheric temperature.

MATERIALS AND METHODS

Study area and period: Madurai is one of the oldest cities and the third largest city in Tamil Nadu, South India. Agriculture and animal husbandry are the major occupation in the surroundings of the study area. Five sites, Anaiyur (urban), Iyer Bungalow (urban), Thabal Thanthi Nagar (urban), Tiruppalai (semi-urban) and Oomachikulam (rural) from Madurai North were selected for the present study. The climate of Madurai is semiarid. In summer, the temperature goes up to a maximum of 42°C and in winter it reaches up to a minimum of 18°C. Human beings and animals become the hosts for anthropophilic and zoophilic mosquitoes, whereas, cultivable and native vegetation provide food for phytophilic mosquitoes. The field study was conducted in selected sites from January, 2015 to December, 2016 in a systematic way. Monsoon showers enhance the breeding habitats of mosquitoes in and around the selected site, in addition to stagnant sewage, water bodies (channel, pond, tank, lake) and the adjoining paddy fields filled with rain and storage water. The survey was done during peak hours (18-10 h) of a day for the collection of adult mosquitoes and meteorological data [Temperature (°C)] was recorded and compared with online sources (www.imdchennai.gov.in) from time to time (Table 1).

Collection of mosquitoes: To study the density and distribution pattern of mosquitoes, periodic collections of adults were carried out at the selected sites. Adult mosquito collections were made according to the method described by Pandian and Chandrashekaran[8]. To collect maximum number of mosquitoes, both the indoor and outdoor collections were carried out between the peak hours in the morning and evening in selected places including cattle shed, moist places and plantations around. All the collected mosquitoes were preserved for identification.

Identification of mosquito species: Clean vials were used to collect the mosquitoes and they were killed with ether and preserved in vials (4.5×2.5 cm), labelled with area of collection to assess the density of mosquitoes in the site. The field collected preserved mosquitoes were spread on a white sheet of paper and *Aedes* species were separated. The male and female mosquitoes were distinguished by observation under Carl Zeiss Stemi DV4 Stereo binocular microscope. *Aedes* species were identified using the keys of Rueda[9].

Data on the distribution pattern of mosquitoes revealed that the dimension of spatial distribution in the selected study sites. Based on the density, the mosquitoes were grouped into 5 categories (0-20% sporadic, 20.1-40% infrequent, 40.1-60% moderate, 60.1-80% frequent and 80.1-100% constant). Interestingly, the distribution pattern "C" was 100 indicating the constant nature for all the sites[10]. Data indicate that, the occurrence of the vector species was uniform. However, the density of the mosquitoes varied significantly in the sites during different months, indicating the impact of climatic factors on their distribution.

Statistical analysis: Meteorological data was correlated with the population of mosquitoes collected from the study sites. Principal Component Analysis (PCA) was carried out using PAST (version 2.17c).

RESULTS

Temperature was recorded from all the selected sites. Minimum, maximum and average temperature was determined (Table 1). Average monthly temperature was correlated individually with mosquito population for each of the site (Table 2). Correlation between temperature and density of *A. aegypti* population for the period of January-December, 2015 (Fig. 1) and January-December, 2016 (Fig. 2) are shown.

Data depicts that a significant correlation exists between temperature and the mosquito population in all the selected sites. During the study period the average monthly temperature ranged from a minimum of 26°C in the month of January, 2015 to a maximum of 32°C in the month of July, 2015, similarly, a minimum of 26°C in the month of January and December, 2016 to a maximum of 34°C in the month of May, 2016.

Invariably, with the raise in temperature there was a corresponding decline in the number of individuals in the population of the vector. Interestingly, a decrease in the vector population 162 (23, 31, 42, 35 and 31, respectively) was

Table 1: Meteorological data obtained during the study period (2015-2016)

		Temperature (°C)		
Years	Months	Minimum	Maximum	Average
2015	January	18	32	26
	February	20	36	27
	March	22	38	30
	April	21	41	31
	May	23	38	31
	June	24	39	31
	July	25	39	32
	August	24	39	31
	September	22	38	31
	October	23	35	28
	November	21	33	26
	December	21	31	26
2016	January	19	33	26
	February	20	35	28
	March	23	40	30
	April	23	40	32
	May	27	42	34
	June	25	38	31
	July	24	38	30
	August	25	37	31
	September	24	38	31
	October	24	38	30
	November	21	34	28
	December	18	34	26

Table 2: Distribution pattern of mosquitoes collected from the sites

		Collection area					
Years	Months	S1	S2	S3	S4	S5	Total
2015	January	160	149	131	132	118	690
	February	120	99	102	84	71	476
	March	52	54	56	48	42	252
	April	81	56	73	50	45	305
	May	31	33	56	39	21	180
	June	90	36	99	62	52	339
	July	23	31	42	35	31	162
	August	40	26	52	37	33	188
	September	46	58	56	45	42	247
	October	77	51	85	67	63	343
	November	145	152	167	131	109	704
	December	133	148	152	128	97	658
2016	January	158	147	129	130	116	680
	February	118	97	100	82	69	466
	March	50	52	54	46	40	242
	April	79	54	71	48	43	295
	May	29	31	54	37	19	170
	June	88	34	97	60	50	329
	July	21	29	40	33	29	152
	August	38	24	50	35	31	178
	September	44	56	54	43	40	237
	October	75	49	83	65	61	333
	November	143	150	165	129	107	694
	December	131	146	150	126	95	648

S1: Anaiyur, S2: Iyyar Banglow, S3: Thabal Thanthi Nagar, S4: Tiruppalai, S5: Oomachikulam

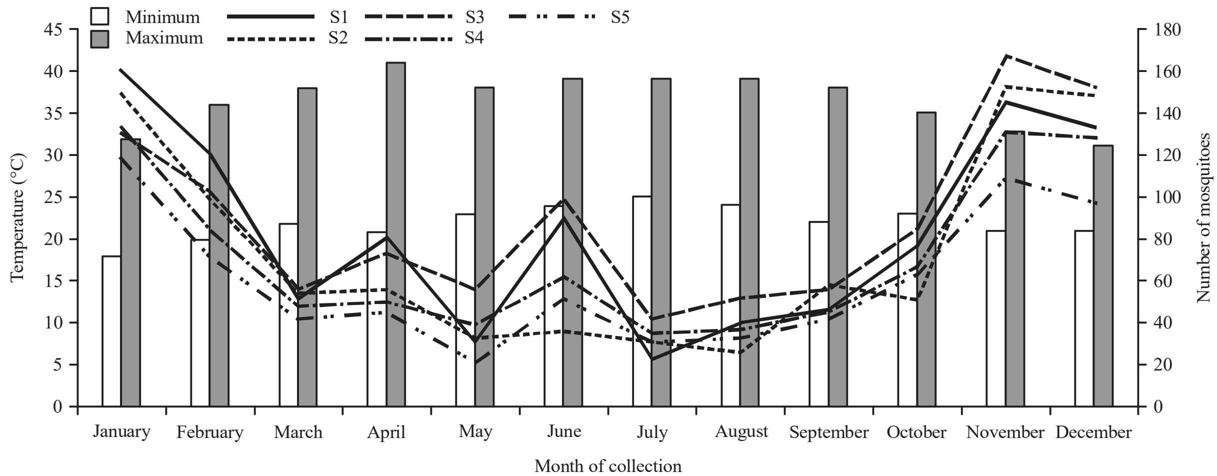

Fig. 1: Correlation between temperature and density of *A. aegypti* population during January-December, 2015
S1: Anaiyur, S2: Iyyar Banglow, S3: Thabal Thanthi Nagar, S4: Tiruppalai, S5: Oomachikulam

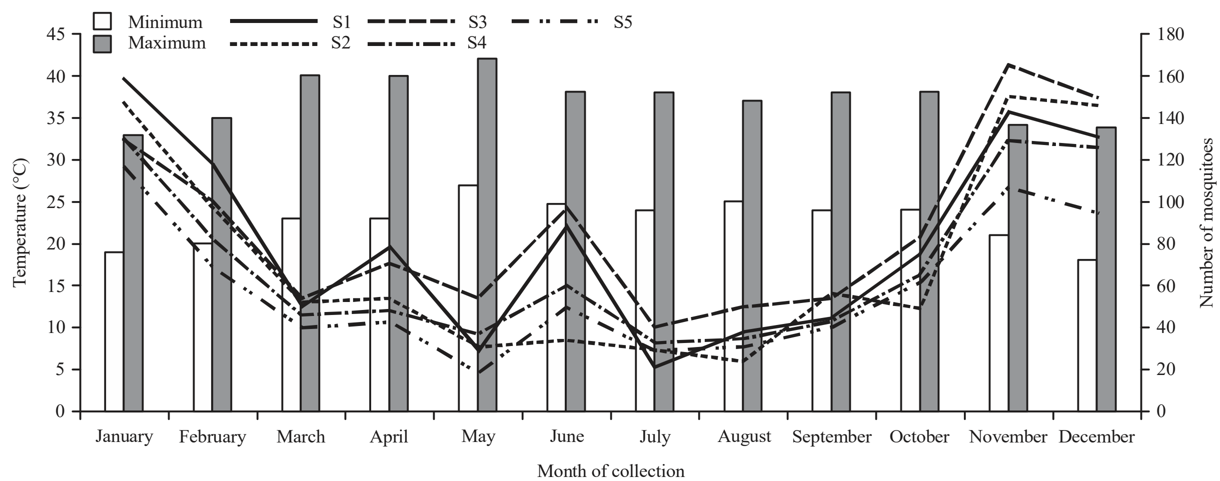

Fig. 2: Correlation between temperature and density of *A. aegypti* population during January-December, 2016
S1: Anaiyur, S2: Iyyar Banglow, S3: Thabal Thanthi Nagar, S4: Tiruppalai, S5: Oomachikulam

observed from S1, S2, S3, S4 and S5 during the month of July, 2015 when a maximum temperature of 39°C was recorded as shown in Table 2. Almost, a similar trend was observed in the successive year also with a total minimum of 170 numbers with a corresponding value of 29, 31, 54, 37 and 19 from S1, S2, S3, S4 and S5, respectively in May, 2016 with maximum temperature of 42°C. However, least population of 152 was observed in the month of July, 2016 where the maximum temperature was 38°C, on the other hand, the winter months with a minimum average temperature of 26°C during the month of January, 2015 and 2016, respectively. The total number of increased population for all the sites were 690 and 680, respectively (Table 2).

To ascertain the significance of temperature as key climatic parameter, Principal Component Analysis (PCA) was performed for each of the sites. Analysis of temperature as PC indicated that temperature as a parameter had a positive correlation (Fig. 3a-e). Furthermore, overall PCA shows temperature as positive climatic parameter that contributes to the reduction in the number of individuals with the raise during the summer (Fig. 3f). In general, there was a similar trend in both year-long cycle of the study period. In specific the trend followed a similar pattern in the year adding to the complication of spread of the disease in the study area. This study implicates temperature as the most significant factor that determines the vector population of an area.

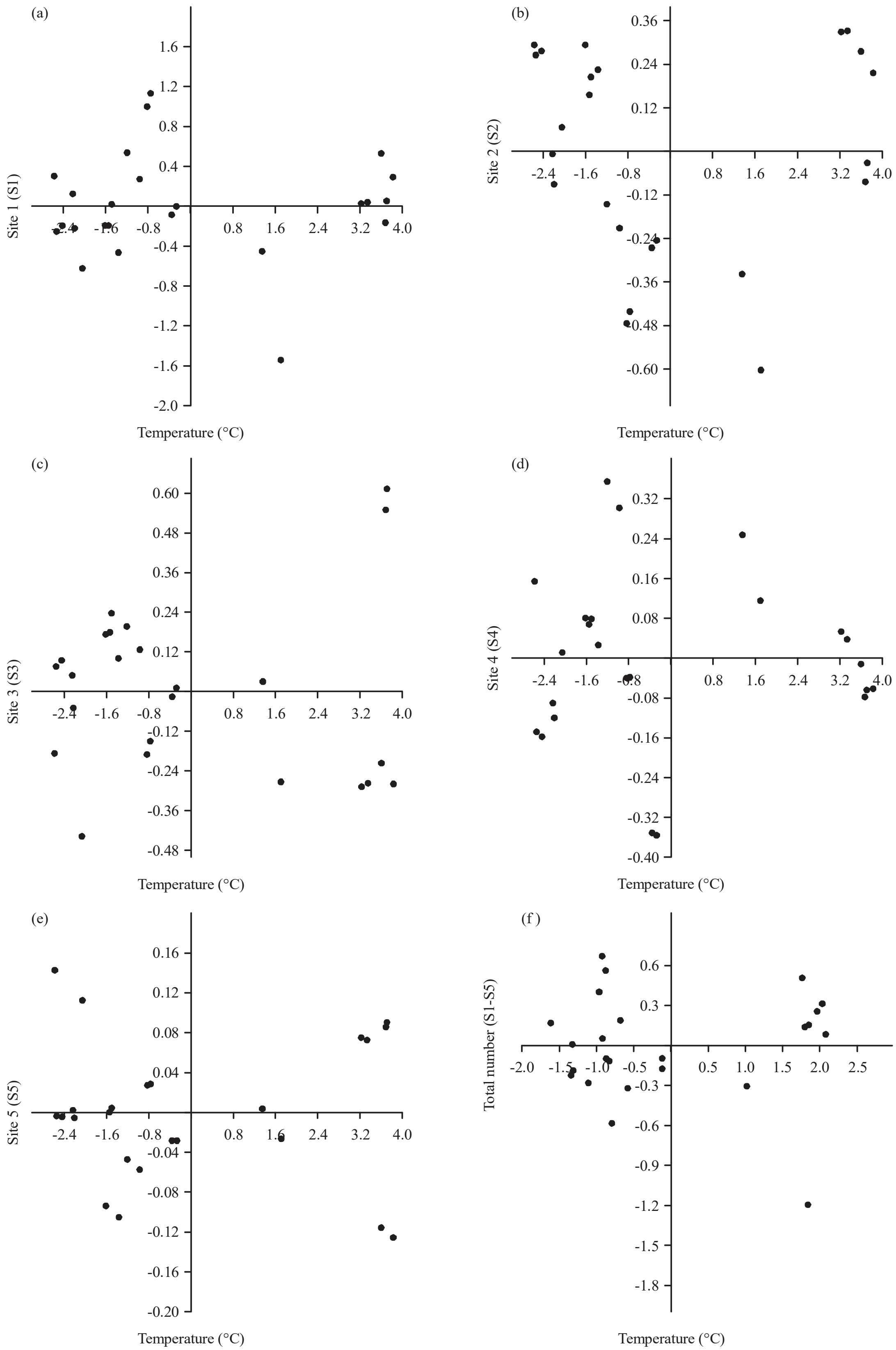

Fig. 3(a-f): PCA for the effect of temperature on population of *A. aegypti*, (a) S1, (b) S2, (c) S3, (d) S4, (e) S5 and (f) S1-S5
S1: Anaiyur, S2: Iyyar Banglow, S3: Thabal Thanthi Nagar, S4: Tiruppalai, S5: Oomachikulam, S1-S5: Overall

DISCUSSION

Temperature of the environment alters mosquito population dynamics by affecting the development of the immature stages (i.e., eggs, larvae and pupae) as well as reproduction[11]. Temperature has a detrimental effect, both species poikilothermic and small-bodied physiology at aquatic larval stages[12-14], with critical isothermal limits inhibiting emergence to the adult stage altogether[15]. Additional variables explored include daily, monthly and annual minimum, mean and maximum air temperature and diurnal range[16,17]. Another key parameter that affects population regulation is ground and surface temperatures, which can significantly prolong or shorten life expectancy as vectors at immature stages are often restricted to small cryptic habitats with strong density dependence effects[13]. This is further complicated by the vector's unimodal response to temperature, egg overwintering behaviour, anthropogenic microclimates and secondary effects of temperature-driven stage transition[18,19].

Data depict that temperature as a climatic variable had a positive correlation with the prevalence of mosquito population for each of the site. Patz *et al.*[20] examined the influences of climatic factors on infectious diseases. It was emphasized that temperature influences developmental rates, mortality and reproductive behaviour of the mosquitoes. Due to the ability to tolerate and withstand a broader temperature range besides other climatic factors, *Aedes* has been successful in expanding its territory range, globally[21]. *Aedes aegypti* is one of the species most favoured by changes in the environment caused by urbanization. Studies have shown that this mosquito species have high degree of flexibility to adapt to anthropogenic induced environmental changes due to the process of urbanization and industrialization to undergo rapid population expansion[22].

It is noteworthy that different results have been published for this species across studies, depending on the region of the tested populations and their tolerance to cold. The lower temperature threshold for *A. aegypti* to develop is 16°C, while 34°C is the upper limit[23]. At a lower temperature (i.e., 8), larvae are motionless and die within a couple of days. Couret *et al.*[13] showed that the development time from hatching to adult emergence was shorter at higher temperatures (30 vs. 21°C and correlated with density and food availability. Bar-Zeev[24] reported that the time taken by larvae to complete their development was optimal at 32°C and the highest temperature was 36°C. The mortality was significant at 14 and 38°C. Furthermore, 40°C was attributed to be the thermal upper limit for *A. aegypti* females, while immature stages were found to survive short exposure to temperature up to 45°C.

CONCLUSION

Expansion of dengue is expected to increase due to climate change, global warming, globalization, travel, trade, socioeconomic aspects, urban planning and human settlement besides the evolution of the vectorial capacity and the virus. No vaccine or specific antiviral therapy yet exists to address the growing threat of dengue. Prompt detection for advance clinical management however can reduce mortality rate. However, the effects of precipitation regimes and seasonality on diseases are still poorly studied. Thorough validation of models is still a challenge and is complicated by a lack of field and laboratory data. Present study results concluded that the dynamic atmospheric temperature can significantly determine the vector population. Higher temperature range during the months of April-June negatively affects the vector population in the region. Ambient low temperatures are positively related to the increase in vector population. Therefore, this field based model system with temperature as a significant climatic parameter could be used as a tool to plan for eco-friendly vector management strategies.

SIGNIFICANCE STATEMENT

This study discovers the naturally occurring underlying relationship between the mosquito population and dynamic atmospheric temperature that can be beneficial for the assessment of dengue outbreak in a region. This study will help the researcher to uncover the critical areas of dengue vector population linked with temperature that many researchers were not able to explore. Thus, a new theory on assessment of the weather-vector population connection is expected to advance efforts to control vector population and disease spread locally and globally may be arrived at.

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